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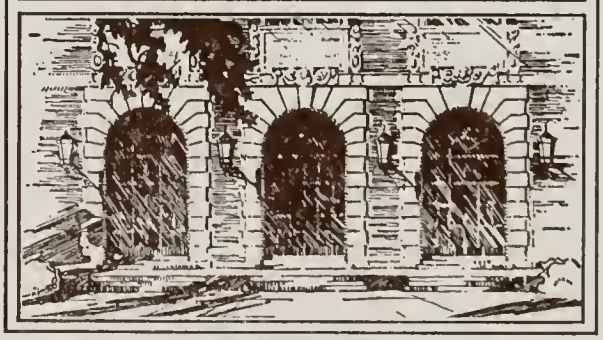

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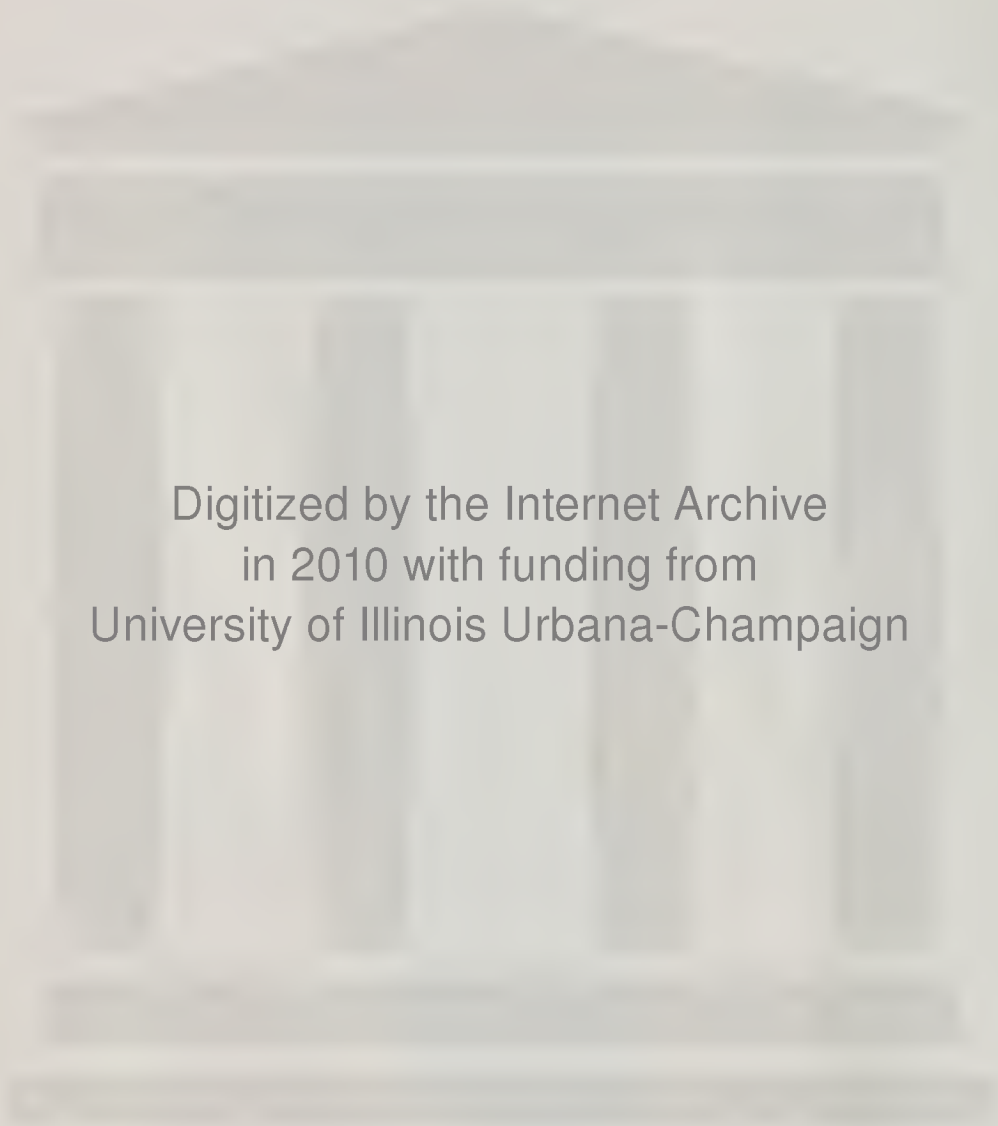

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A STUDY OF THE GEODESIC DOME APPLIED TO HOUSING:
Introduction and Annotated Bibliography

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In Conjunction With Duke-Ritchie Associates

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A STUDY OF THE GEODESIC DOME

APPLIED TO HOUSING

by

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University of Oregon
In conjunction with Duke-Ritchie Associates

The following study was undertaken by DUKE-RITCHIE Associates, a professional team of Urban Planning Graduate students from the University of Oregon, and represents four months of full-time graduate team research. The study may be viewed as an initial thrust into the field of alternative housing forms having potential for easing the housing crisis in the United States and elsewhere. It is intended that this study should familiarize those in the housing field with both the positive and the negative aspects of the Geodesic Dome as conceived by R. Buckminster Fuller.

Should additional information be desired, the reader is invited to contact DUKE-RITCHIE Associates personally.

Sincerely,
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TABLE OF CONTENTS

Introduction..... 2

Geodesic Geometry and Structure..... 4

Application of Geodesic Framing System to Housing..... 8

Materials and Techniques..... 14

Potential Markets for Geodesic Dome Houses..... 17

Annotated Bibliography..... 22

INTRODUCTION

The following study of geodesic domes was initially undertaken in the hope that it might point toward a partial solution to the lower cost housing crisis in the United States. (The primary focus of the study has been the Northwestern U.S.) Since the geodesic framing system is based on "synergetics," or the science of doing more with less, this system appears to offer at least a valid starting point for a look at the problem of housing costs.

This study has both disappointed and satisfied our hopes. Despite its simplicity and structural elegance, the geodesic dome is not alone capable of very substantial reductions in house cost. Even forgetting, for the moment, the cost of land and of financing, the cost of the house frame and shell represents only a small portion of total house costs. The substitution of geodesic domes for half-cubes will not lower land, financing, and interior finishing costs.

Substitution of the geodesic dome for the half-cube will not lower even the costs of the exterior shell by any significant amount as long as fabrication relies on hand-craft methods and materials are dominated by wood.

The geodesic dome will work well in a system of factory fabrication of precision parts from light weight, high tensile strength materials. If production is measured in thousands of units per year, the cost of the shell can be lowered significantly. Similarly, it appears that assembly line production of "utility cores"--one unit bath-room, kitchen and climate control packages--will lower the costs of the house interior. Combined, these technologies would provide a very liveable "core house" at a very low unit cost. This core housing would find a sizeable sales market among people interested in buying a house for a low initial investment and finishing it themselves, thereby lowering their financing costs; it would find an even larger rental market among college students, young singles, and others interested in finishing or decorating their rental units with a high degree of individuality.

There are also growing indications of a market for conventionally finished geodesic houses, both in the primary housing market and in the vacation housing market. Using conventional materials (primarily wood) geodesic domes have already entered these markets; using the types of materials capable of exploiting the particular advantages of geodesic domes, thereby lowering purchase and operating costs, the conventional housing market for geodesic domes could no doubt be expanded.

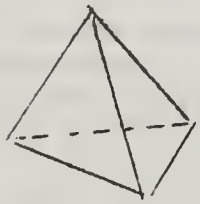
Another application of geodesic domes which merits closer examination is the "environmental fence" concept: a plastic covered dome which would protect the entire living area, house as well as yard, from the elements, thereby rendering the conventional house obsolete.

Although the geodesic dome has already attracted some market interest as an inexpensive alternative to the conventional half cube, it will soon be competing for attention with several other inexpensive alternatives. Some of these other alternatives are already on the market; others are still in the testing stages. However, the geodesic dome must be considered in the context of all the attempts to find new forms to lower housing costs: the geodesic dome is not by itself a solution to the housing crisis. Many other systems have been adapted or can be adapted to assembly line production: numerous other systems merit further serious study.

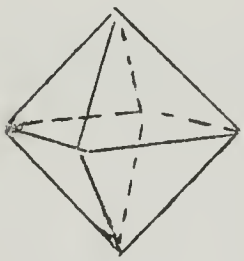
Perhaps the most significant thing about the geodesic concept is the underlying logic. It is becoming increasingly important that the entire housing industry, if not all of industry, begins to think in Fullerian terms of "more with less" regardless of house form to be used. Indeed, there is almost certainly a need for numerous structural forms to meet various housing needs. The geodesic dome appears to have great potential to fill the housing requirements of some people.

GEODESIC GEOMETRY AND STRUCTURE

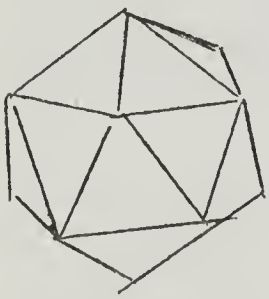
In order to understand the advantages of the geodesic framing system it is helpful to have at least a cursory knowledge of the geometry of the system. A quotation from R. Buckminster Fuller's book, Geometry in Action will serve as an excellent introduction to the concept of the geodesic dome:



Tetrahedron



Octahedron



Icosahedron

Spherical Icosahedron

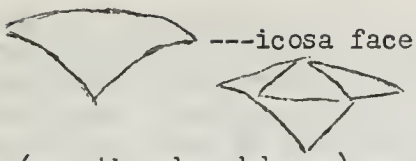
....the tetrahedron is the basic geometric form, because all other regular angular structures can be made up of tetrahedra, but the tetrahedron cannot be subdivided into component polyhedra of less than four facets.

The geodesic dome is a combination of the virtues of the tetrahedron and the sphere. The sphere's virtue: it encloses the most space with the least surface, and is the best container--the strongest against internal (and radial) pressures. The tetrahedrons: it encloses the least volume with the most surface, and is the stiffest form against external (and tangential) pressures....

In order to approach the sphere, Fuller compounded tetrahedra into an octahedron, then into an icosahedron, the geometric form with the highest number of identical & symmetrical surface truss facets of all polyhedra.

Then, in a sense he exploded the icosahedron onto the surface of a sphere enclosing it. This divided the surface of the sphere into a number of spherical triangles, or triangles with three bowed legs. Another way to picture this is to imagine an icosahedron made of rubber, into which air is pumped until it swells into a sphere with all its former edges now lines on the sphere's surface. Each one of these lines is then actually a segment of a great circle, i.e., a great circle arc.

Fuller took the chords to these great circle arcs, removed some, added more members, and came out with a 3-way grid, all of whose vertices lie on the surface of a sphere. So he has a trussed structure which quite closely approaches



---icosa face

(or other breakdowns)

the shape of a sphere--close enough for half of it to be called a dome. The dome gets its name from the arcs, which are called geodesics.[1]

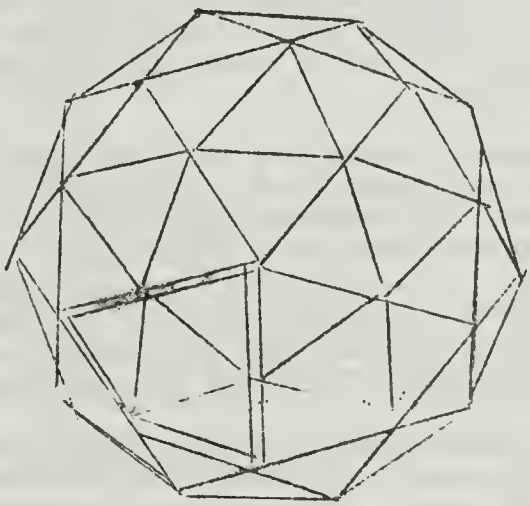
From the concept of geodesic arcs follows the concepts of "breakdown" and "frequency." These can be described as an attempt to expand the icosahedral form to satisfy the space requirements and allow the components from which it is made to remain within structural fabrication and erection limits.

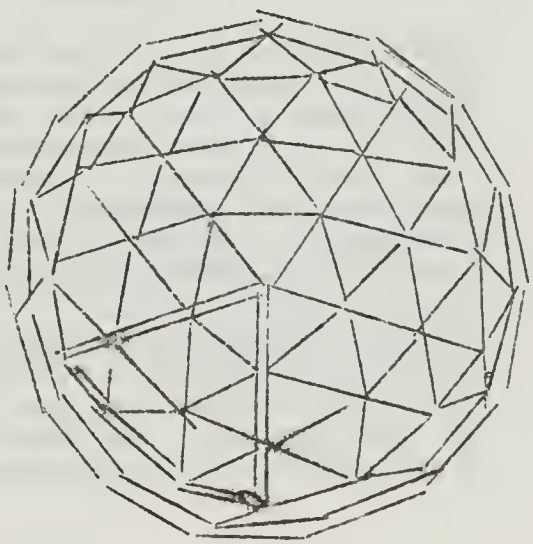
"Breakdown" refers to the method by which the face of the icosahedron is subdivided so that only triangles are produced, each triangle approximating the symmetry of the equilateral icosa triangle. Two methods of achieving this are used, the "alternate breakdown" and the "triacon breakdown."

To achieve the "alternate breakdown" the face is divided by lines from each edge to the opposite edges. "Frequency" refers to the number of equal or nearly equal parts into which the icosa-edge is divided by the starting points used to achieve the breakdown. In either the alternate or the triacon breakdown, the greater the frequency, the greater the number of chords and facets. Hence, the greater the frequency, the more closely the dome approaches the shape of a true sphere.

As the following diagrams illustrate, the repeating patterns in an alternate breakdown can be completely represented in one icosa-face. For all frequencies greater than two, the icosa edge is subdivided into slightly unequal lengths.

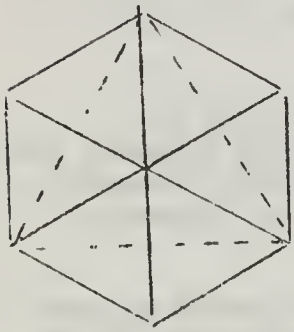
Two-Frequency Alternate



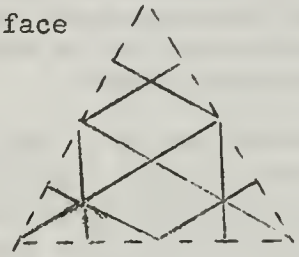


Three-Frequency Alternate

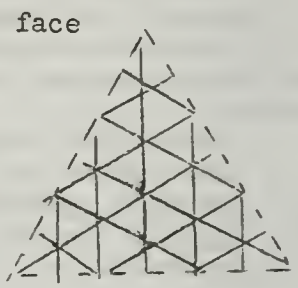
In the alternate breakdown, the edge of the icosahedron (or the edge of the tetrahedron or octahedron if these are used) is part of the grid, and thus is represented in the structural members. By contrast, this is not so in the triacon breakdown. The first division of the face is made from the center of each edge to the opposite vertex and subsequent divisions are made parallel to the first, subdividing each edge into the same number of equal parts. Therefore the triacon breakdown only works on even frequencies.



Two-Frequency



Four-Frequency



Six-Frequency

In order to maximize the advantages of a geodesic structure, it is necessary to select the proper frequency and breakdown for the intended use, size, and material. However, there are several advantages common to all geodesic domes.

Because the structure of a geodesic dome is self supporting, it requires no internal or external support systems, and can be assembled with a minimum of construction equipment. The geometry of the dome transfers a stress on any one point outward in concentric circles so that every structural member in the dome resists a force exerted upon any one member, and each member acts tensionally as well as compressionally. This greatly reduces the quantity of material required to support the structure and to resist a given load upon the structure and permits the use of materials with high tensile strength to maximum advantage.

A dome encloses the greatest amount of space with the least proportional surface area. The enclosing surface of a hemisphere is always twice the area of its base. The enclosing surface of a half-cube, (the most common shape for a one story frame house) is three times the area of the base. Since the geometry of the geodesic dome gives more assistance to the load bearing members in its frame than does the geometry of a half cube, a half cube will require at least 50% more material than a hemisphere to perform the same function.

Additional advantages include a minimum surface area for heat transfer, superior rain and snow shed and minimum resistance to omnidirectional air motion, reducing heat loss by "drag." The dome also encourages the experience of living space as volume, rather than area, opening up new design and life-style possibilities.

Following is a brief history of the geodesic framing concept in its various applications.

In the late 1940's, Fuller set up several corporations to correlate his various activities; Synergetics and Geometrics, Inc., for prototype and pre-production development arising from civilian and government needs and the Fuller Research Foundation to carry out pure and theoretical applied research.

Although Fuller kept the patent for the geodesic dome and his corporations participated in the exploitation of the patents only to a minor degree, various external corporations, including Kaiser Aluminum Company, Union Tank Car Co., and such home-construction companies as Pease, obtained geodesic dome fabrication liscences, to build domes for a wide variety of purposes. For each dome built, under current arrangements, a liscencee agrees to pay Fuller 5% per square foot of surface area of the dome itself.

The first geodesic dome to attract wide scale public attention was the dome over the Ford Rotunda building, which Fuller designed in 1953. Meanwhile, Geometrics, Inc., was busy developing the Radomes for the Arctic "Dew Line," and Synergetics was at work on the Marine Corps Shelters project which, in 1954, produced a 36 ft. diameter hangar for helicopters and a 14 ft. six man paperboard shelter. The six man shelter, using less than $10.00 worth of materials, was designed to be discarded after use, leading the GI's to dub it the "Kleenex House." The Marine Corps tested these and other domes for over two years, resulting in the development of a 42 ft. dome capable of satisfying over 89% of the Corps' shelter needs. Other domes have been built for the Marines, who now employ several different sized structures to shelter both men and aviation equipment in the field.[2]

Since the success of the Ford Rotunda Dome in 1953, the geodesic dome has been applied to numerous other large scale space needs, including a motel restaurant at Woods Hole, Massachusetts, a convention-concert hall at Kaiser's Hawaiian Village, a botanical garden in St. Louis, a bank in Oklahoma, a tank car refurbishing facility in Baton Rouge, Louisiana, the Expo dome in Montreal, a county office building complex in California, and others. In the late 1950's, the portability of the geodesic dome was discovered by several U.S. agencies who began using the domes to cover travelling exhibits, trade fairs, etc., around the world.

Various companies interested in the application of geodesic domes turned out a variety of low cost, smaller diameter domes and dome kits. At first regarded as novelties, these dome-homes have recently begun attracting increasing serious attention, and utilization for permanent year-round housing as well as for vacation and other specialty shelter uses.

APPLICATION OF GEODESIC FRAMING SYSTEM TO HOUSING

The shape of the geodesic dome has many advantages in application to the design of housing, and some disadvantages as well. The dome shape is particularly suited to air circulation, heating, and ventilation. Not only does the shape present a smaller exterior surface than a half-cube or an A-frame for the loss or gain of heat, the shape creates a smaller "drag," or heat-draining turbulence in its lee during a wind storm.

If the interior is preserved from excessive divisions and if the interior walls, lofts, etc. are designed with proper air flow in mind the natural spherical flow of an air system will effect the heating or cooling of every part of the dome with equal efficiency; a rather small climate control strategically located near the center of the dome will serve the entire house. There are no dead air corners to trap cold or warm air and encourage heat transfer with exterior air.

Of course, if the interior space is improperly divided the air circulation advantages of the dome shape may easily be lost; for example, fully enclosed rooms or lofts will definitely impede air flow. Furthermore, the shape of the exterior itself increases the difficultly of completely segregating internal spaces by rigid, permanent walls, because of the necessity of cutting practically every member for an internal wall to fit. For these reasons, a family desiring a conventionally divided house of several totally separated rooms may find a dome less desirable than a conventional half-cube structure.

Aside from the unique problems of separating internal spaces, the dome presents a number of interesting problems and opportunities for interior design and decoration. Although the dome will compete well with box housing on the basis of floor space measurement, particularly with a loft or second floor, the space in a dome is best measured and designed as volume rather than area. Once this is done, the internal space in a dome can be divided and demarked in numerous ways to flow and change flexibly, according to the needs and tastes of its inhabitants.

Unlike the box house, the shape of the dome is quite rigidly fixed. For design purposes, this structure may be compared to the fixed structure of a sonnet, and the individuality achieved by the architect of a dome home may be compared to that of the architect of a box home in a way similar to the comparison of the creativity of a sonnet poet with the creativity of a free verse poet. If the architect or interior decorator heeds the geometry of the dome, consisting as it does of almost equilateral triangles repeated in a precise pattern, this geometry will dictate his designs and he will place windows, trim, and furnishings so as to express the personality of the dome's inhabitants and meet their living needs.

Of course, it is possible to ignore the geometry of the dome; to do so would produce a feeling of psychological discomfort in a design-oriented person but might have no effect at all on someone else.

If the geometry is to be worked with, rather than against, the lofts should be tied in at any of the hubs and may or may not extend completely to the skin of the dome. Interior walls should also be located with attention to the position of hubs and icosa faces, and/or should stop well short of the exterior of the structure. Large square or rectangular interior rooms are to be avoided, and the interior layout will most easily be designed over a hexagonal grid.[3] Any wall joining the exterior should meet it as closely as possible at a right angle to the tangent at the point of intersection.

When the interior is divided minimally the result will be an expansive flow of space in three directions from any viewpoint. Partial lofts, half walls and articles of furniture will help to structure and direct this flowing feeling. Patterned or random window placement may also be used to great effect, whether full or partial face triangular windows or smaller rectangular windows are used. A very small amount of transparent or transluscent window opening near the top of the dome will provide a great deal of natural light for the entire space, and assist in orienting the interior spaces.

Even the smaller domes have room for at least one loft, supported either by load bearing walls or by pillars; the larger domes permit the introduction of multi-level lofts, which may be used both to increase the usable floor area of the dome and to structure the flow of space, air, sound and light.

The acoustics of a dome become critical, due to the echo-focussing characteristics of the shape. Unless the interior surface is treated to absorb most of the sound which strikes it, the interior should never be left entirely open; if it is, sounds from anywhere in the dome will focus at a point about half the dome's radius below the center. Similarly, sounds emanating from this general vicinity will fill the entire structure. This location would be a good location for speakers of a sound system; it would be a very poor location for a bathroom. If a sound system is to be installed at this location, advice of an acoustic engineer should be sought, both to determine the proper material for coating the interior and to determine the exact speaker placement which will achieve the most desirable results.

The reflective geometry of the dome shape will also serve a heating and/or lighting system well. A location near the focal point of the dome would be desirable for a radiant heating system and for a central lighting system, as well as for a sound system; a partial loft suspended at this point to support these systems would also assist in breaking up the echoing of sounds from other parts of the dome.

Air circulation and venting systems must take account of the natural air flow characteristics of the dome as well as the manner in which the interior spaces of the dome have been divided. Fuller suggests a variable opening vent system worked into the top pentagon of the dome, which will encourage the co-operation of the natural convection currents inside the dome with the currents set up above the dome by virtue of its shape. A properly insulated dome with a well designed venting system would probably require no air conditioning at all.

As is true of any other house form, the proper solution of acoustic, climate control, and lighting problems, as well as the division of interior spaces inside a dome, will probably raise the cost of the shelter considerably. However, the lowering of maintenance and operating costs and the increased comfort of the home will quickly compensate for the added initial investment.

Furthermore, the proper utilization of the spatial characteristics of the dome home may permit lowering of the initial costs of the house in other ways. For example, with a dome it is quite simple to contain most or all of the plumbing and most of the wiring in a common utility core, occupying the wall separating the kitchen from the bathroom, without producing any significant inconvenience for dome inhabitants. Further cost reductions are achieved by minimizing the number of interior walls; bedrooms and other privacy areas may be surrounded by lightweight, mobile walls which permit the almost spontaneous expansion or contraction of various living spaces within the dome.

Because of the regular, repeating geometry and the design possibilities in window placement and loft construction, the interior of the dome, however sparsely furnished, will not look bare in the same way that a similarly sparsely furnished cube will. This permits and even encourages the use of fewer and less expensive furnishings in the dome with additional savings. In fact, much of the conventional heavy, expensive furniture used in conventional houses will not fit well into a dome at all, except along interior walls.

The separation of the exterior from the interior structure and the lower level of decoration and furnishing required by a dome permits the dome to be used easily in "core housing."[4] A permanent dome is built, complete with finished floors, loft(s), bathroom and kitchen appliances and a wall surrounding the bathroom. This core may be sold to a homebuyer, who then can inhabit the core while he finishes the interior himself, to his own taste, or who may pay off the mortgage on the original structure before taking another loan to finish the interior, thus realizing substantial savings on financing costs. This core house could also be rented to students, young singles, families between houses or otherwise unable to buy a home, and others to whom the considerably lower rent would present an incentive to spend a small investment in finishing the interior temporarily to their own needs and tastes.

Such a core house could well be built with a translucent skin and snaps or other connectors along the struts inside the dome, so that opaque panels could be snapped on to alter the light and heat intake patterns according to the changing season and the needs of the inhabitants. Such a dome would provide the first truly flexible living quarters, capable of almost complete transmogrification. Whether occupied by owners or renters, the interior could be altered almost at will without permanent change to the structure itself; the arrangement and decoration of the interior would change as easily as the furniture arrangement in a present day home.

While modern trends in interior decoration have moved steadily toward the concept and reality of flowing, rather than compartmentalized space, the psychological impact of living with curves, or many small planes, rather than a few large planes, is difficult to assess. Doxiadis' speculates that the human tendency to "flatten all curves" approaches the level of a psychological need to be surrounded by planes rather than curves. Whether this can be elevated to the level of a general law, it no doubt applies to some. Certainly the dome home contains no long, high, flat wall to lean against for either physical or mental support. Furniture would tend to group away from walls; there would be no safe corner to retreat into--nor would there be corners to "get backed into." It would be difficult inside a dome home to provide the womb-like security of a tiny enclosed space, commonly associated with one's "room." The dome is capable of providing almost any degree of isolation from and privacy in relation to strangers and the community at large, but internal privacy, separation from others in the same home, will be achieved only with some difficulty. In fact, the dome's principle characteristic is probably its integration of various functions into one flowing living space, it's "togetherness." The dome works best when the bulk of interior space is open to permit the expansion of some living functions and contraction of others on either a rhythmic (day and night) or an eventual basis. It does not lend itself to a high degree of differentiation (TV room, game room, parlour, dining room, kitchen, separate family areas and guest areas). A family that "gets on each other's nerves" will not enjoy living in a dome nearly so much as a family that enjoys almost constant physical, verbal, or visual contact with one another.

Although domes can be and have been constructed in any size, with numerous lofts, they work best in smaller scale. A very large dome, unless amply provided with windows and interrupted by some form of interior partition or loft, can be an intimidating as a limestone cave. Problems of acoustics, lighting, heating, and control of spatial flow increase geometrically with the increasing size of a dome, and a larger dome will sacrifice many of the positive features of a smaller dome. Despite the increasing economies of larger domes, some of the most successful adaptation of domes to shelter have used two, three, or more smaller domes with minimal division for separate rooms or room clusters.

On the larger scale, at least two applications for geodesic domes should be considered. For example, a large (sixty foot diameter, for example) dome could quite easily be divided into five pie-shaped segments for use as multiple family units, with a common utility core in the center. Each unit could be three or four stories; well over a thousand square feet of living space per unit is possible.

Another interesting application of the dome is the "environmental fence," a low rise (less than a quarter diameter) dome with a diameter of sixty feet or more covered with a combination of transparent and transluscent materials, double layered for insulation and provided with venting and other appropriate climate control devices, covering the entire living area, both what is normally considered to be "indoors" and what is normally considered to be "outdoors." Living spaces such as bathrooms and bedrooms would be separately enclosed within this environmental fence by opaque walls; kitchen, dining, and entertaining spaces could be provided platforms without walls, perhaps in scattered areas around the dome, separated by vegetable and flower gardens, lawns, a swimming pool, etc. If the site contained natural rock outcroppings, trees, and other interesting features, they could easily be covered and included inside the fence to become part of the living space. Such an environmental fence would be expensive, but not prohibitively so.

Potential builders of dome-homes might encounter some difficulties in gaining community acceptance of this form, particularly in conservative or property-value conscious communities, due to it's obvious and striking variation from "traditional" house styling. In fact, a dome built in a neighborhood of closely packed conventional houses might seem "out of step." However, if kept in scale and properly finished, the dome might provide a much needed relief from the sameness of the surroundings.

On the other hand, a street lined with domes might run the risk of excessive sameness and repetitiveness. Again, if scale and materials are used sensibly, the effect could be as attractive as the effect of repetition of construction form is in many European villages, where the repetition of forms with minor variations often forms one of the most attractive parts of the landscape. The repetition of the dome form will in fact permit the expression of individuality in small, tasteful ways without these small touches being drowned in a sea of non-unique "differentness." The selection of trim,placement and orientation of windows, selection of trees and plantings, etc., will become much more effective. Such a development might adopt the appearance of a field of different sized and colored mushrooms, or it might be designed to blend so completely with the natural surroundings as not to be noticed at all. It might, in fact, easily be argued that the multiple repetition of geodesic dome houses could not possibly be worse than the multiple repetition of "ranch-types."

Potential builders of dome homes may find difficulty fitting them into prevailing patterns of land subdivision and zoning requirements. The problem is not one of technical difficulties with compliance but rather one of efficient land use. Normal set-back requirements and rectangular or square lot shapes definitely come into question.

Preferable lot shapes for a geodesic dome development would probably be either equilateral or nearly equilateral triangles, hexagons arranged around curved streets, or pentagons with interspersed triangles of common land. Domes will fit, of course, onto conventional lots, but they will not make the best use of the land.

By loosening set-back requirements for geodesic domes, housing density can be greatly increased without substantially affecting privacy. If bedrooms and bathrooms and other utility functions are confined to the lower floor, the living space can occupy the loft(s), which will be several feet farther back from the property line than the ground floor. Furthermore, the windows in the loft, or second floor will recede, giving the effect of looking upward and outward, rather than downward and outward, as with vertical windows. The net effect would be to permit the placement of domes on very small lots, while permitting a view over and between adjoining houses, rather than into adjoining houses, as with many conventional housing developments.

If a dome is to be set on a conventional rectangular lot, set-back requirements should probably be interpreted as applying to the average protrusion of the structure, rather than to the base extremity. This will permit undue wastage of the lot while preserving whatever function the set-back requirement is intended to serve. If the round shape is felt to be out of place in a particular setting, it can easily and attractively be altered by the addition of porches following the structural geometry of the dome; appropriate plantings will also enhance the graceful effects and soften the unremitting curvature of the dome.

MATERIALS AND TECHNIQUE

Wood is the current most popular construction material for geodesic dome houses, due primarily to its availability and familiarity. The struts of the geodesic dome frame are most commonly 2 x 4's or 2 x 6's (a three frequency alternate breakdown geodesic dome, for example, joins the strut members at an angle varying about seven degrees from a plane), the strut connector system is the most problemstic aspect of constructing a dome shell on site. For this reason several firms, including Dynadomes of Phoenix, Arizona, and Domebuilders of California, have begun prefabricating and marketing hub kits to dome builders. Domebuilders Co. sells two types of pre-cut, pre-bored disc hubs for various sizes of domes, and Dynadomes sells clamp type hubs, which fit around ends of the 2 x 4 or 2 x 6 struts. Judging from Dynadomes' sales report and correspondence with dome home builders, most wood framed domes built with on-site construction techniques use prefabricated hub kits to ensure precision and to cut on-site labor costs.

Plywood sheathing seems to be the most common exterior covering material. Most of the dome homes visited by the researchers used plywood sheathing and, in some cases, plywood exterior finish. The 39' diameter three frequency dome, which seems to be the predominant size for houses, was obviously selected with plywood in mind. The 39' size permits one face panel to be cut from a standard 4 x 8 sheet of plywood with minimum wastage. Splicing and additional framing to receive nails is required, of course, to make the walls sufficiently rigid.

On-site cutting and jointing is, by no means, the only construction technique for wood geodesic domes. At least two California firms are selling prefabricated triangular exterior wall panels with self-contained struts. Two sizes of wall panels are used for the 39' three frequency dome, and they are bolted together on site. Though on-site construction is made easier by the prefabricated wall panel system, there is the disadvantage of using more material for framing than is structurally necessary. The pre-framed panels marketed by the two California firms, in effect, double the thickness of the struts, adding substantially to the weight the structure has to support.

Sealing and insulating the wood geodesic domes requires perhaps more care than any other phase of construction. For any dome less than a half sphere the entire exterior surface is, in effect, a roof; the surface is directly exposed to precipitation. Since there are numerous joints in a geodesic dome, sealants become critical. Following is partial list of sealants: 1) rubber sealing tape which applies to plywood with a liquid adhesive; 2) coated cloth tape which has flexibility to permit expansion and contraction; 3) polyurethane plastic which adhers to surface joints; 4) elastomeric membrane which is highly flexible and water impermeable; 5) acrylic film which can be used to coat plywood surfaces.

To avoid the problem of moisture condensation in the space between the exterior skin and the interior skin it is necessary either to seal completely both surfaces so that no moisture can be trapped between the skins or to leave "breather" holes on the exterior surface. The latter can most easily be accomplished by leaving shielded openings at the hubs.

Heat insulation of the wood geodesic dome can be achieved by relatively conventional materials and techniques like stapled batting or by more innovative systems like sprayed urethane foam. The former has the advantages of availability and familiarity and the disadvantage of labor consuming cutting and fitting. The latter has the advantages of quick application and, with certain foams, providing a complete moisture seal. One possible technique is spraying foam directly onto the interior surface and covering it with wire mesh, forming a mechanical bond for plaster or other finish materials.[5]

Acoustical insulation for the interior spaces, a substantial problem with the dome form, can be partially achieved by using rough, sound-absorbent materials for the interior wall finish. Rough textured foam plastic, wood, or fabrics are particularly suitable. It will be the interior space dividers and lofts, however, that provide the greatest barriers to sound echo in the dome house.

Though the preceeding discussion focused on wood as the principle material for geodesic dome homes, it was not intended to imply that wood is the most suitable material for dome home construction. Since the geodesic dome relies primarily on tension members rather than compression members for its structural strength, new light-weight materials with high tensile strength are more appropriate both from the standpoint of efficient material utilization and from the standpoint of structural soundness. The large geodesic domes like the Ford Rotunda Building and the U.S. Pavilion at Expo '67 employed metal alloy strut systems and light-weight face panels of metal and acrylic, respectively. Partly because the house scale dome has not structurally or economically required using the most efficient materials and partly because Americans have a resistance to synthetic materials for home building, metal alloys, plastics, and other light-weight materials have had a very limited application to geodesic dome housing. One of the most unique applications of a non-wood material to geodesic dome housing took place several years ago in "Drop City," Colorado, where a creative work commune built domes of metal sheets formed from junk automobiles.[6] A more recent attempt took place in "Resurrection City" during the Poor Peoples' March to Washington, D.C., where three architects built a 30' dome using triangular sections of polyethylene for the faces of the dome.[7] Both the Drop City domes and the Resurrection City dome used wood strutting systems, however. The most extensive application of new materials was the U. S. Marine Corps' use of treated paperboard for small, temporary dome shelters.

Prefinished, pre-insulated, bolt-together triangular face panels using plastic or metal alloy frames should be developed as prototypes. Among the new light-weight covering materials warranting further investigation for the development of prefabricated face panels is treated paperboard. Universal Papertech of Hatfield, Pennsylvania, has already applied fiberglass covered 5/16 inch paperboard with foam insulation to conventionally shaped houses with a resultant product that is claimed to last twenty years.[8] A similar technique incorporating a foam insulating core could be applied to the geodesic dome.[9] Fiberglass reinforced rigid vinyl, acrylic and rigid urethane foam offer more permanent alternatives while retaining the quality of levity. While transluscent and transparent acrylic has had wide application in skylights and windows of geodesic domes, the material also seems suitable for face panels if coated with a spray-on foam insulation. Rigid urethane foam, which has had application in other structural systems as well as insulating systems, could be molded into the triangular shapes required by the geodesic dome. When coated with a substance resistant to solar rays and braced by a light-weight frame, the urethane panels could probably satisfy requirements for weatherability and insulation. Another covering material warranting investigation for development of prefabricated panels is ferro cement. Light-weight and cheap, ferro cement could be formed in metal frames at the factory and shipped to the building site with substantial cost savings over many other materials.

Interior finishing of any of the prefabricated face panels could be achieved in variety of ways. Prefinished veneer panels could be attached on site or in the factory. Wall board and plaster or plaster applied directly to a wire meshed urethane foam surface would be the relatively conventional solutions. An innovative system, which is appealling from both a practical and an esthetic standpoint, would be pre-cut, snap-on fabric panels. The panels could be removed for washing or cleaning and replaced with ease.

Though the basic shell of a house is a relatively small part of total construction costs, new building materials and techniques should make the geodesic dome highly competitive with other modular and prefabricated housing from the standpoint of cost. In short, new materials and factory production techniques could make the geodesic dome shell a viable alternative to the conventional rectilinear shelter form.

POTENTIAL MARKETS FOR GEODESIC DOME HOUSES

First embraced by innovative architects and members of the "youth subculture" the geodesic dome home is now finding increasing acceptance among a broad spectrum of American people. Geodesic Environments, a San Francisco Bay area dome building company, recently participated at a home show in which it distributed several thousand brochures to prospective buyers from all walks of life. Most of the companies selling dome-building kits and/or complete domes are now operating at full capacity with long backlogs of orders. Orders for geodesic dome homes have come from retired senior citizens, young professionals and businessmen, among others.

Although the geodesic dome manufacturing industry is too young and too small for the determination of long range trends, the increase in interest shown by the public in geodesic domes both for permanent occupancy and for vacation homes suggests a strong future for the industry.

If the industry can introduce the new materials and building techniques which will utilize the full structural advantages of the system, thereby further increasing durability and decreasing initial cost and maintenance, its market potential should increase substantially. By application of appropriate materials and techniques it may well be possible to lower the cost of geodesic dome shelter sufficiently to compete effectively with such current low cost housing techniques as the mobile home, for example, while retaining most or all of the superior performance characteristics of the dome.

In addition to the mobile home, the geodesic dome will be competing with mobile home based modular housing, mandril-fabricated plastic houses, paper-plastic or fiberglass sandwish panel techniques, re-inforced concrete bubbles and other cost cutting techniques now under development.[10] In the vacation housing market, the geodesic dome may be in competition with many of these techniques as well as with the more traditional A-frame, the "pod house" and other low cost packages.

Each of these house building techniques has its own advantages and disadvantages. As noted in previous chapters, the advantages of the geodesic dome include: greater strength with (up to 50%) less material, more efficient heating, cooling, and ventilation, and its capacity for quick, easy on-site fabrication from a minimum of pre-cut parts.

Design advantages of the dome include its high degree of spatial integration and, if the structural system is re-inforced with trim, window placement, etc., design integrity. From any point in the dome, the curvature of the shell gives one a sense of the entire structure, including spaces hidden from view. This is reinforced by the repeating geometry of the strut system, and the placement of windows, trim, etc., can be employed either for further emphasis or to provide striking counterpoint.

This geometry and design integration also permits a much lower level of interior separation and finishing, permiting the inexpensive achievement of an open, flowing living space. However, this integration of space is purchased with a loss of internal privacy and separation of function, which may be further reduced by the acoustic properties of the dome shape. A high level of acoustic and visual privacy inside a dome is achieved only with some difficulty and, usually, at the sacrifice of the visual integrity of the structure.

A certain prestige value may also inhere in the dome for home purchasers in the middle and upper income markets because of its "newness" and uniqueness. For the lower income market this may prove more of a liability.

The "environmental fence" concept should prove quite appealing to the homebuyers in the $30-$50,000 range, particularly in the Northwest where bad weather so severly limits outdoor living. In order to estimate the cost of an environmental fence, it would be necessary to solve the rather intricate engineering problems associated with the concept. If, as appears likely, this large clear dome can be built within a reasonable budget, a sizeable market could quite likely be developed.

The largest market potential for geodesic domes is probably for the core houses. If a basic kit for a completely liveable shell house with a sanitary, kitchen, and heating utility core is priced reasonably, this could be ideal for families unable to bear the burden of financing costs for a home. They could live in the core, finishing the interior as time and money became available. The rental market might prove even larger than the sales market. Large numbers of core houses could be constructed for low cost rental to college students, singles, and others who might enjoy applying part of the rent savings to creative, easily removeable interior partitions and finishing, which could be torn out and redone on a custom basis by each new inhabitant.

The same basic dome kit could be applied to completely finished houses with prices ranging from below $10,000 to $30,000 and higher, to compete in the middle price range. In this market geodesic domes would be competing, primarily on the basis of design, with mobile homes and other standard housing techniques. These dome houses would meet essentially the same market demand now met by currently available domes.

Larger (60 ft. diameter and above) geodesic domes also provide some new design possibilities for multiple family housing. Divided into pie shaped units with a common utility core, the ground floor of these apartments might be used for sleeping areas and bathrooms, with cooking areas and living rooms on the second floor and a study on a third floor loft. The second and third floor windows would look upward and outward, permitting the building of these "pent-plexes" to quite high densities without giving the inhabitants a "closed in" feeling. These pent-plexes could be fully finished, or could be treated as core housing, with only the ground floor finished. However, they would compete on the same market as conventional multi-family housing.

Geodesic domes, like most of the other promising new developments in housing technology, will achieve their full potential only after housing and building codes have been revised to make them more uniform and more flexible. As the codes presently operate, a builder must deal with fragmented "specification" codes, which permit practically no innovations of any sort, or with Uniform Building Code (UBC) standards, which some localities have revised so as to make them almost as restrictive as the codes they replaced.

Under the UBC, an architect or engineer, registered in the state in which the structure is to be built, must attest that it will stand. However, if a particular design is approved by the International Conference of Building Officials (through structural testing) approval under UBC is considerably simplified. This process of approval is necessary for each model of a geodesic dome; alterations in material, specifications, or size, however slight, will necessitate a complete new approval.

Several models of geodesic domes have already achieved ICBO approval, and at least one dome has met FHA standards for financing. On the basis of these and other past experiences, and after a cursory review of building, housing, and zoning codes in the Northwest, it does not appear that these codes will present insurmountable obstacles to the construction of geodesic domes. The primary difficulty is likely to be in obtaining approval of the use of new materials and new building techniques which, in geodesic domes as in other house forms, are necessary if any substantial cost reductions are to be achieved.

Because of the newness of the geodesic dome home, the only reliable indication of the marketability of this concept will be to build one or more prototypes and exhibit them to the public. This can probably be done best by an organization already engaged in manufacturing a product using the lightweight metals and one or more of the other materials appropriate to geodesic dome construction, or by an organization already active in the homebuilding market. In either case, a strategy for testing and simultaneously developing a market would include exhibit of one or more prototypes, preferably full scale, at home shows and fairs plus the distribution of sales brochures both in connection with these exhibits and by mail.

A geodesic vacation home would make a logical addition to a vacation homebuilder's line; a construction firm or others with the suitable fabrication capacity might also be able to bid successively for federal assistance to build a small core housing development, either for sale or for rental. Such a development might well be oriented toward the University of Oregon, either by finding a suitable location fairly close to the university, or by arraging for appropriate transportation.

An aircraft or sheet metal fabrication firm would be in an excellent position to manufacture a strut system; a boatbuilding firm could easily put together the type of plastic, fiberglass, or ferro-cement panels appropriate to domes.

Because the utility core and interior finishing techniques would be similar, a mobile home manufacturer might be the most appropriate potential dome manufacturer of all. Within the mobile home factory exists the metal working capacity, the ability to work with plastics, fiberglass, etc., and the ability to assemble the type of utility core package appropriate to core housing or to low cost finished housing.

NOTES

[1]R. Buckminster Fuller. Geometry in Action, quoted from reprint in the Architectural Forum, August 1951, pp. 145-146.

[2]For description of early domes see: Architectural Record, June 1955 and January 1959, p. 168; Business Week, May 10, 1958, p. 112; Architectural Forum, May 1953, p. 109; New York Times Magazine, August 23, 1959, p. 14.

[3]For illustrations of hexagonal floor plans see Architectural Forum, November 1948, p. 38.

[4]For a good discussion of the application of core housing to cities in the developing world see Charles Abrams, Man's Struggle for Shelter in an Urbanizing World, 1964.

[5]For illustrations of the technique see Architectural Record, August 1968, p. 155.

[6]A pictorial essay about "Drop City" appeared in the Architectural Forum, September 1967, p. 74.

[7]The "Resurrection City" dome and other uses of plastics for building are discussed in Industrial Design, July 1968, p. 33.

[8]For a description of the paperboard technique see the Science Digest, June 1970, p. 39.

[9]A small (22') paperboard dome was manufactured by the Fome-Cor Corp. See the Science Digest, June 1961, back cover.

[10]For more information about new materials and techniques see Annotated Bibliography.

ANNOTATED BIBLIOGRAPHY

Books

Abrams, Charles. Man's Struggle for Shelter in an Urbanizing World. Cambridge: MIT Press, 1964.

Probably the most extensive treatment of the developing world's housing problems written to date. Abrams ties the almost global problems of urbanization, squatter settlements, urban land shortages, government power and policy, foreign aid, and development economics to the multi-faceted problems of providing shelter in an urban setting. He discusses comparative housing policies, financing barriers, different housing programs, and even different building techniques in the book.

A must for anyone seriously interested in the field of housing.

Fuller, R. Buckminster. Ideas and Integrities. Prentice Hall, 1963.

A spontaneous autobiographical disclosure. Fairly good account of Fuller's idea of the universality of domes; not limited to shelter uses. Discusses the history of domes, separated into two main classes of technology.

Chapter 8 - "Domes, Their Long History and Recent Development."

Fuller Research Foundation. Dymaxion Index. Published by Fuller Research Foundation, 1953.

Bibliography and published items about the dymaxion concept and Fuller, 1927-1953.

Good sources for information prior to 1953 and at the inception of the geodesic dome concept. Includes chronological index of publications mentioning Fuller and the dymaxion concept, copy-right and patent number, memorandum of articles by Fuller, and Fuller's public presentations.

President's Committee on Urban Housing. A Decent Home. Washington, D.C.: U. S. Government Printing Office, 1968.

A good comprehensive study of federal housing programs followed by policy recommendations. Its bias is toward bringing the private sector into housing research and development and increasing the industrialization of housing production.

Points to the need for more factory produced components to housing, whether the housing follows conventional forms or new forms like geodesic domes.

Marketing Research Department, McGraw-Hill Information Systems Co. The Report of the President's Committee on Urban Housing. Washington, D.C.: U. S. Government Printing Office, 1968.

Contains selected technical studies of urban housing costs, production efficiency, financing, labor, and land availability prepared for the President's Committee on Urban Housing.

Of particular relevance to the study of the geodesic dome structure and its capacity to reduce housing costs are Sections IV. A. and IV. B., the former showing cost breakdowns for new construction and the latter presenting discussion of rationalization of housing production and institutional barriers to rationalization. Both sections explicitly point out that the basic structure of a dwelling is proportionally a small part of total housing costs.

Pacific Domes. Domebook One, 1970.

The first instruction book directed toward the do-it-yourself geodesic dome home market (The Dome Cookbook preceeded it but did not focus specifically on geodesic domes). Includes fundamental geodesic principles, chord factors for various domes, suggestions for materials, an intrcduction to spherical trigometry, illustrations of different models and dome houses, and instructions for strut and skin connector systems.

The book is essential for anyone wishing to build a dome from scratch.

Popko, Edward. Geodesics. Detroit: University of Detroit Press, 1968.

Probably the most comprehensive treatment of geodesic geometry in print. Popko begins with a discussion of basic polyhedra and moves into explanations of alternate and triacon breakdowns, orientation, and chord factors. The text is only nine pages, the remainder illustrations with subscripts.

Rapoport, Amos. House Form and Culture. Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1969.

An excellent look at the interaction of the social, cultural, economic, and physical forces that determine house form in "primitive" societies. Rapoport, an architect, used the cultural anthropologist's method of observation to develop his thesis (or hypothesis) that the socio-cultural variables are the most important determinants of vernacular house forms. Different cultures with similar physical environments, he points out, have developed radically different house forms.

Of particular interest is his observation that the unself-conscious design process of the more primitive cultures often responds better to the needs of dwelling occupants than the professionalized design process of the more developed societies. Such an observation lends support to the idea of core housing, which permits the occupant some freedom to complete the design process to fit his needs.

Schorr, Alvin. Slums and Social Insecurity. Washington, D.C.: U. S. Government Printing Office, 1966.

The theme of the book is that the social, economic, and physical forces at work in the provision of housing for the American people are not geared toward relieving the housing problem of the poor let alone eradicating their poverty.

Chapter I discusses the correlation between housing and health, behavior, and attitude. It offers, implicitly, some criteria for judging the adequacy of housing, which might help in evaluating the dome form.

Chapter II discusses physical design of housing and its effect on the life styles of the poor. The chapter is important reading for anyone attempting to apply domes to housing for the "hard-core" poor. The need for acoustical and visual privacy for large families with night workers is a good example of its relevancy to geodesic dome housing.

Professional Journals--related to Architecture

AIA Journal. June 1970, p. 67. "The Non-Dymaxion World of Buckminster Fuller," by William Marlin.

This article gives a brief anecdotal sketch of the application of some of Fuller's ideas to the profession of architecture.

Architectural Design. March 1960, p. 101. "Universal Requirements Checklist," by R. Buckminster Fuller.

In parallel columns, Fuller's exposition of an outline for determining man's shelter requirements is compared to some of the solutions he has proposed.

This is an important beginning point for anyone interested in domes, or in practically any other technology for industrialized housing, alternate forms of home ownership, etc.

Architectural Design. July 1961, p. 290. "Richard Buckminster Fuller," ed. John McHale.

A long letter in which Fuller compares himself to the Bauhaus is followed by a fairly complete summary and translation of Fuller's design philosophy. Included is a discussion of Fuller's concept of house as "energy valve" which suggests a new approach to shelter systems.

This article, plus the March 1960 article (above) should be read first by anyone beginning a study of Fuller's ideas of shelter systems. A careful reading of each article will take 3-5 hours.

Architectural Design. January and April 1970, also contain articles of interest.

Architectural Forum. November 1948, p. 38. "Letters"--a letter from Mr. Anton Kratochvil, President of Circular Homes, Inc.

Mr. Kratochvil writes that his firm was able to produce circular houses for $1000-2000 less than comparable rectangular homes. The floor plan sketch may be of some interest to prospective dome builders.

Architectural Forum. August 1951, p. 144. "Geodesic Dome."

A very comprehensive treatment of the geodesic dome framing system in theory and in application. Provides a good introduction to geodesic principles and the advantages of tension structures.

Architectural Forum. May 1953, p. 109. "Bucky Fuller Finds a Client."

A descriptive article about the geodesic dome built over the Ford Rotunda Building, the first major application of the system.

Architectural Forum. March 1961, p. 128. "Bamboo Geodesics."

A short article about a 60 ft. diameter bamboo strut dome built at a Fuller symposium in California. Fuller speculated that this type of dome, built of bamboo and fishing twine, could be covered with low cost plastic film to house the poor in Asia.

Architectural Forum. March 1966, p. 40. "Repetition without monotony."

A photographic essay about the necessity for individuality and variety in house form. Shows the use of repeating house forms in several Mediterranean villages and cities, where the scale is appropriate and the effect pleasing. This article might provide inspiration to the student interested in the effect of clustering a community of domes or other factory produced housing.

Architectural Forum. September 1967, p. 74. "Drop City," by Charlotte Trego.

A short illustrated article about the commune in Colorado that built geodesic dome dwellings from old automobile tops, an appealing "subculture" attempt to utilize recycled waste to meet shelter needs.

Architectural Forum. January 1969, p. 96. "Tinkertoy Houses."

A scheme for industrialized housing with precast concrete interlocking parts. Of particular interest is the idea of replaceable and interchangeable house parts.

Architectural Forum. Articles of interest will also be found in the following Architectural Forum issues: May 1949, March 1954, December 1954, January 1956, March 1957, March 1958, June 1958, November 1958, July 1965, June 1966, July 1968, March 1970, April 1970.

Architectural Record. June 1955, p. 155. "Cycles of Evolution."

Fuller writes his philosophy about how architects came to be what they are, and about what they will become. The article includes a pictorial history of Fuller's early inventions, including some of the early applications of the geodesic dome.

Architectural Record. October 1957, p. 269. "Technical Roundup: Fuller, Students Build Geodesic Pine Cone."

A news brief containing a description of a prototype plywood dome built by Fuller and some Cornell students. Particularly interesting is the technique of overlapping additional plywood sheets to eliminate the need for weatherproofing.

Architectural Record. January 1959, p. 245. "Useful Curves and Curved Surfaces: 28-Geodesic Domes," by Seymour Howard.

A good three page summary of the principles of geodesic geometry, with a discussion of the properties of the tetrahedron and the sphere and showing the breakdown of icosahedral faces. Popko's book, Geodesics (see above) may be a better source.

Architectural Record. October 1961, p. 159. "Geodesic Gym Gives More For Less."

A short article about a geodesic dome which won the design competition for a gymnasium by providing more usable floor space at slightly less cost. The article includes a brief comparative cost table comparing the dome to a conventional structure.

Architectural Record. March 1967, p. 187. "Finally: A Low-Cost Component System for Housing That Really Works."

Description of a system of 32' pre-tensioned precast spanning planks and precast load bearing walls. The 32' length permits spanning a sufficiently long distance for design flexibility and conforms to existing material requirements (4' widths).

Architectural Record. August 1968, p. 155. "Urethane Foam Insulation Suits Electrically-Conditioned Apartment."

Illustrates the application of polyurethane foam insulation to walls. 3/4 to 1 inch of foam was sprayed onto the wall then a 1 inch wire mesh applied to permit bonding of plaster directly over the foam.

Architectural Record. September 1969, p. 207. "Load Bearing Sandwich Panels Form Weather-Tight Skin."

Description of a load bearing sandwich panel developed by Phelps Dodge Building Materials. The sandwich usually consists of metal outer skins, vinyl spacers, and a polyurethane insulating core. The urethane foam is applied to the panels in the factory; foam is applied to the joints on site. This system would work well with the Geodesic Dome.

Architectural Record. October 1969, p. 131. "Toward 'A Decent Home for Every American Family," by Margaret Farmer.

The author contends that "Operation Breakthrough" aims at "controlling," not lowering the cost of housing through changes in construction technology.

Architectural Record. April 1970, p. 137. "Operation Breakthrough," by Robert Jensen.

An explanation of the mechanics and goals of the program with brief resumes of the proposals submitted by the twenty two finalists in the Breakthrough competition. A list of site planners follows the article.

Architectural Record. October 1970, p. 148. "Building Process in the 1970's," by Robert E. Fischer.

Discusses the dangers of too loosely thinking and talking about the "systems" approach to building. The author contends that the mystique and vagueness of the "systems approach" has become a refuge for clients wishing to escape making decisions about their building needs.

Architectural Review. July 1956. "Buckminster Fuller," by John McHale.

A biography of Fuller's work with pictures. Quite readable; well worth the 30-45 minutes required.

Arts and Architecture. February 1951, p. 22. "The Comprehensive Designer," by R. Buckminster Fuller.

Here Fuller discusses with relative brevity the principle of synergetics and its relationship to the comprehensive man and the comprehensive designer.

Arts and Architecture. August 1958, p. 20. "Plydome Vacation House," by Marquis and Stoller.

An illustrated article about a 25' plydome house built for the San Francisco Art Festival. Includes an interior photo and a floor plan for the dome, using only two small partitions.

Arts and Architecture. April 1958, p. 14. "'Shell Truss' Space Frames in Florida," by Jeffry Lindsay.

A brief illustrated article about space framing systems using aluminum and stainless steel struts. The article suggests a silicone coated dacron fabric weatherproofing cover.

Ekistics. October 1968, p. 395. "Ekistic Synthesis of Structure and Form," by C. A. Doxiadis.

Doxiadis postulates a theory that man needs horizontal floors and ceilings and straight walls. Early man, he argues, came into conflict with curved surfaces and invented flat surfaces to meet innate psychological needs. This article is important for anyone interested in the possible psychological effects of the dome, and for anyone investigating the concept of space efficiency.

Industrial Design. February 1961, p. 64. "Fuller's Latest Dome Arises," by Judith Ransom Miller.

A description of the "bamboo geodesics" project in which the dome shape was modified to a cone to simplify the structure for use of primitive materials (bamboo and fishing twine).

Industrial Design. July 1968, p. 33. "Better Living Through Chemistry?" by Paul Sargent Clark.

This article describes various schemes to use plastics in housing, including on-site formed epoxy resin foam walls and floors, developed by Midwest Applied Science Corp., West Lafayette, Indiana, and all plastic bathrooms offered by Crane and American Standard. A plastic skinned dome built at Resurrection City by three Washington area architects (Jeff Sussholz, Jim Hammill & Jan Beeman) is also described.

Industrial Design. July 1970, p. 54. "Helping Hand."

A description of a simple self-help module system fabricated by "Calverton Industries," a co-operative company in Calverton, Eastern Long Island.

Interiors. July 1952, p. 80. "After the Modern House...," by George Nelson (report of a Frank Lloyd Wright address.)

This article explores and amplifies the concept of a house as a space container, or a shell conditioned to serve the living requirements of the inhabitants. Includes photos of a model and description of a project to be undertaken by the FLW foundation in conjunction with Fuller, combining the "space container" and the "environmental fence" concepts.

Interiors. May 1954, p. 18. "How to Print a House and Why," by Olga Gueft.

Discusses the implications of the paper geodesic dome developed by Fuller for the Tenth Triennale in Milan for meeting the basic shelter needs of the world. Paperboard domes could be printed on printing presses; a 36 foot dome skeleton would weigh only half a ton and could be assembled by unskilled labor using minimal tools.

Interiors. November 1954, p. 114. "Cardboard Geodesics from the USA," by Olga Gueft.

Description and photos of the Triennale Exhibition cardboard domes, covered with vinyl "bathing caps." One was used to shelter a cactus display and the other was furnished by architect Roberto Mango as a vacation house. The hexagonal grid based floor plan is quite interesting.

Interiors. Other articles of interest may be found in the following issues of Interiors: June 1949, October 1951, August 1953, April 1954, and June 1954.

National Scuptural Review. Spring 1970, p. 17. "Geodesic's Dome for a Sculptor's Studio."

Illustrated description of a geodesic dome built to serve as a studio.

Perspecta. Number 1, 1952, p. 29. "New Directions 3--Buckminster Fuller."

Fuller discusses the advantages of the geodesic dome. The article also discusses the "autonomous dwelling facility" and the "environmental fence."

Perspecta. Number 2, 1953 also contains a relevant article.

Perspecta. Number 11, 1967, p. 59. "Vision '65--Summary Lecture," by R. Buckminster Fuller.

In this lecture Fuller discusses his philosophy of "more with less," among other things. "If humanity understood that the real world problem is that of upping the performance per pound of the world's metals and other resources, we might attempt to solve that problem deliberately, directly and efficiently."

Progressive Architecture. June 1954, p. 101. "Geodesic Dome Restaurant--Woods Hole, Massachusetts."

Illustrated description of a motel restaurant.

Progressive Architecture. June 1960, p. 141. "Plastics in Architecture."

A series of articles discussing the advantages and disadvantages of structural uses of plastics. Although the technical data is 11 years old the articles suggest many things important to consider when thinking about using structural plastics.

Progressive Architecture. June 1965, p. 188. "Lighting," by Abe Feder.

Discusses problems of lighting a large dome. A big dome is over-whelmingly larger than human scale: Feder suggests lighting it to give an impression of an exterior rather than an interior, to prevent it from seeming like a cave. The size range within which domes may be built and retain psychological comfort may be limited by existing lighting technology. Although Feder addresses his discussion to the large scale dome, many of his observations and some of his specific suggestions may be applicable to the lighting problems of smaller domes as well.

Progressive Architecture. March 1966, p. 192. "Good Room Proportions Improve Acoustics," by Michael Rettinger.

Rettinger suggests alterations of the standard acoustic proportions (three formulae all about 1:2:3 height:width: length) to accommodate domes. He suggests a radius twice the ceiling height or more; if a higher ceiling is used, vibrations should be broken up by a false ceiling. Although Rettinger is writing of large domes to be used for large gatherings, his comments apply also to smaller residential sized domes.

Progressive Architecture. July 1967, p. 156. "Spun Plastic Shapes a School."

Describes a cheap fabrication method developed by the Dow Chemical Co. The use of eight domes of thin shell expanded polystyrene by the Roeper City and County School in Bloomfield Hills, Michigan reduced costs from $17 to $13 per sq. ft.

Progressive Architecture. July 1967, p. 167. "Dr. Dante's Dome."

Doctor Dante Bini of Italy devised a method for forming thin-shell reinforced concrete between two inflatable membranes. The structures, costing about half as much as a conventional structure, have been built all over Italy and were being tested at Columbia University by Dr. Charles W. Thurston.

Progressive Architecture. September 1967, p. 154. "Calks and Sealants: How Do They Compare?" by Oscar L. Vaughan.

This article is a "must" before selection and application of sealants.

Progressive Architecture. February 1968, p. 124. "Glue Building... Revisited."

Gives the pros and cons of a nail-less building, with all joints glued, which was built several years earlier by architect Richard Sharp. Also discusses public reaction to the concept; after an article in P.A., Mr. Sharp received only one letter; after a similar write up in a mass distribution man's magazine, he received hundreds of inquiries.

Progressive Architecture. February 1968, p. 139. "Total Furniture."

Illustrated description of a $2000 living module including everything but a bathroom designed by Amannut & Vitelli of Italy. An interesting take-off point for ideas about new concepts of "shelter" and "home."

Progressive Architecture. February 1968, p. 141. "Prefab Geodesic Domes Cover Offices."

Administrative Offices for Auburn (Placer County) California, built on clustered hexagonal bases by TemCor. Aluminum exterior with sprayed-on asbestos thermal and acoustic insulation.

Progressive Architecture. June 1968, p. 195. "Lowering the Cost of Housing."

A long article discussing the obstacles to lowering housing costs and illustrating some hopeful signs, followed by a long section devoted to new plans, some in progress and some in the drawing board stage, including (p. 126) a module utility core designed by Ken Fryar Associates and Ronald Goodfellow.

Progressive Architecture. April 1970, p. 120. "Operation Breakthrough Operation P.R." by Don Raney and Suzanne Stephens.

Contains a summary of Breakthrough objectives and an illustrated list of winning proposals.

Progressive Architecture. April 1970, p. 134. "Forgotten Breakthrough," by H. Z. Rabinowitz and James Stanek.

Describes a 1941 Defense housing project which attempted some of the same things being attempted by "Breakthrough," and draws a few interesting comparative conclusions.

RIBA Journal. July 1968, p. 300. "The Personal Element in Housing: An Argument for Open-ended Design," by Amos Rapoport.

Rapoport argues convincingly for a flexibility in design which will permit the occupant of a housing unit to exercise a degree of creativity and self expression in "finishing" the dwelling. His concept is similar to the "core housing" concept, though he approaches it from a different vantage point.

The following Journals also contain articles of interest:
Studio, June 1970 and May 1970;

UNESCO COURIER, July 1965.

Other Periodicals

American Fabrics. Spring 1953, p. 100. "Textile Mill of Tomorrow," by R. Buckminster Fuller.

Description of a design for a multi-story textile mill covered by a geodesic dome. This article is of interest primarily as an illustration of the new volumetric thinking made possible by the geodesic dome.

American Home. March 1955, p. 20. "The Walls are Closing," by Jean T. Anderson.

A critical article about a small vacation home with a large multi-purpose room, relevant to geodesic dome home design.

Better Homes & Gardens. June 1957, p. 72. "What Do You Know About the Geodesic Dome?" by K. Olson and A. Miller.

A good popular history of the geodesic dome, with fairly good photos.

Better Homes & Gardens. September 1969, p. 62. "Whatever Happened to the New Building Ideas of a Few Years Back?"

Case studies of what went wrong with selected past housing "breakthroughs" including some good utility core ideas.

Better Homes & Gardens. August 1970, p. 30. "Home Financing."

Presents five "new" alternatives to the traditional mortgage.

Business Week. September 3, 1955, p. 44. "Plastics: A Bite at Homebuilding."

Illustrated news article about a conventional shaped styrofoam panel house built in Houston by Dean Emerson, a styrofoam dealer.

Business Week. May 10, 1958, p. 112. "Fuller's Domes Catch on at Last."

Brief history of the geodesic dome. Includes data on the Kaiser and Union Tank Car Co. domes.

Business Week. March 7, 1970, p. 32. "Where Housing Will Break New Ground."

Gives a thumbnail sketch outline of the "breakthrough" grants.

Changing Times. October 1970, p. 15. "Can We Ever Build Cheaper Houses."

A good introduction to the components of the problem of housing cost reduction, touching on land cost, increasing space per person, and construction technology.

Fortune. April 1966, p. 170. "People in Plastic Houses."

Illustrated article about an accordion fold house designed for California migrant workers with 340 square feet of floor space for $500. A basic utility core is estimated at another $800 or so.

House Beautiful. September 1968, p. 92. "R. Buckminster Fuller Talks About Transparency," by R. B. Fuller.

Fuller kicks off a burst of metaphysics starting from a discussion of the transparent window.

House Beautiful. October 1968, p. 133. "The One-Day House," by John H. Ingersoll.

An informative article on "modular housing" of more historical than technical interest.

House Beautiful. February 1969, p. 6. "Drop In, Fold Out, Add On."

Brief description of a system to permit room-by-room designing or adding on, starting with a 336 sq. ft. module.

House and Garden. March 1967. "A Box Unboxed."

A description complete with floor plans and photographs of a conventionally shaped two story house that permits a lot of vertical space, using a low ceiling in part of the living area and soaring high ceilings in other parts; an effect achieved easily with a geodesic dome.

Life. June 8, 1953, p. 67. "Tape, Plastic, and Aluminum--Ford Builds a Geodesic Dome."

Good photo-essay on the construction of the Ford Rotunda Building.

Life. December 3, 1956, p. 85. "A Plastic Igloo for an Eskimo."

Six inch styrofoam blocks designed to replace snow in igloo construction, permitting igloo use in summer as well as winter. (The problem is, Eskimos like to move around a lot. But the application of the insulating properties of foam plastic is nevertheless interesting.)

Life. October 6, 1961, p. 85. "The Ballooning Boom in Domes."

Pictorial article about three domes, beginning with a 134 foot Radome, an inflatable plastic balloon theater, and a Pittsburgh Public Auditorium Dome with sliding room sections. Good pictures but little text.

Look. August 23, 1966, p. 56. "Buckminster Fuller--Dean of the Dome."

Short popularized history of Fuller and the Geodesic Dome, written after preparation of his model for the U.S. pavilion at Expo '67.

The July 10, 1970 issue of Look also has a brief article of interest.

Monthly Labor Review. May 1970, p. 60. "Labor Costs and the Rise in Housing Price," by Nat Goldfinger.

Analysis showing that construction costs are falling as a proportion of total housing cost and that financing costs are rising. On-site labor costs have fallen from 33% of the total in 1949 to 18% in 1969, suggesting that labor cost is not the most important obstacle to reducing the cost of housing.

New York Times Magazine. July 25, 1954, p. 36. "Living Under a Dome," by Betty Pepis.

A one page popular interest article about the new concept of dome houses. Included good photographic illustrations of the interior of a dome-roofed living and the exterior of the Florida bubble dome designed by architect, Eliot Noyes.

New York Times Magazine. August 23, 1959, p. 14. "The Breakthrough of Buckminster Fuller," by Robert Marks.

A good popular biography of Fuller as he began to rise in prominence.

Catalogs many of his inventions and lists some of his early geodesic domes.

New Yorker. January 8, 1966, p. 35. "Profiles in the Outlaw Area."

Good overview of Fuller's life, his accomplishments, and their far-reaching implications. Gives a sampling of the scope of his research; for example, molecular biologists have discovered that the mathematical formula for the geodesic dome applies perfectly to the structure of the protein shell surrounding every known virus, and possibly the same formula explains the basic structure of the atomic nucleus. Provides an excellent summary of his philosophy and the roots of the geodesic dome concept.

Popular Mechanics. August 1956, p. 89. "The Latest from Paris--an All-Plastic House," by Leone and Lester Hayes.

A popular interest article about the world's first all-plastic house. The walls, ceilings, and floors are plastic; the windows, plexiglass, and the utility units, molded plastic.

Most interesting are the single-mold plastic bathroom unit, combining toilet, bath, sink, and cabinets in one unit and the single-mold kitchen unit. The floor plan of the circular house also might have an application in geodesic domes.

Popular Mechanics. October 1956, p. 193. "Here's Your House of the Near Future," by Jay Doblin.

The concept presented in the article is building the house structure around prefabricated service cores--bathroom core, kitchen core, power core, entertainment core, and communications core--which can substantially reduce construction cost.

The idea has application to geodesic dome houses as well as conventional house forms.

Popular Mechanics. March 1959, p. 102. "They're Testing Tomorrow's Homes," by Kenneth Anderson.

Comments on new building techniques and materials being tested by the National Association of Home Builders Research Institute.

Insulated "sandwich" wall panels, sashless windows, caseless doors, plastic plumbing and water consumption reducing toilets and garbage disposals are some of the more interesting ideas included. Though old, the article still presents some new sounding concepts.

Popular Mechanics. April 1969, p. 172. "Rondette--Prefab House in the Round."

Photos and floor plan of round prefabricated vacation homes, priced from $3840 for a one bedroom to $6702 for a three bedroom. The floor plan suggests ways of handling interior space in geodesic domes.

Popular Science Monthly. December 1955, p. 81. "He Built His House of Foam."

Discusses Dean Emerson's successful efforts to build a house of styrofoam in Houston, Texas. Francis J. Niven, Houston engineer, designed a method of gluing the styrofoam panels together at their sides, tying the stack on both sides with steel wire strung between a timber plate and concrete slab, and spraying an inch of concrete or plaster on both sides. The walls had twice the compression strength required by building code and withstood a 200 mph hurricane. The insulating effectiveness made possible heating and air conditioning units one third the size of standard requirements.

Popular Science Monthly. December 1961, p. 75. "Bucky Fuller's Wonderful Dome."

Good popular account of Fuller's domes and other accomplishments. Mentions Pease Woodworking Co.'s geodesic dome houses and Monsanto Chemical Co.'s dome shelters of paperboard and foam.

Science Digest. June 1961, back cover. "Modern 'Igloos' offer Low-Cost Shelter."

Article about a plastic-foam and paperboard sandwich geodesic dome made by "Fome-Cor Corp."--jointly owned by Monsanto and St. Regis Paper Co. The 22 foot, 350 lb. kit sold for $300 in 1961.

Science Digest. June 1970, p. 39. "People Who Live in Paper Houses."

A description of the Universal Papertech Co. paperboard, foam plastic house; cost about $1000 per 400 sq. ft. module. A complete utility core was selling for about $400.

Sports Illustrated. August 11, 1969, p. 42. "A Well-Rounded Way to Live."

Describes Robert Benson's home in Nags Head, N.C., using a cluster of four 39' diameter domes from Geodesic Domes, Inc. Cost figures averaged $13.00/sq. ft. for finished home with appliances.

U. S. News and World Report. November 23, 1970, p. 72. "New Ideas for Breaking the Housing Logjam."

Discusses the U.S. trend toward factory-built homes. Gives a few insights into the marketability of new industrialized housing components.

Vogue. January 1971, p. 124. "New Sense of Living, 1971."

Shows very good interior photos of a three dome cluster in Florida. The domes are connected by breezeways. The owner used contemporary furnishings, emphasizing the spacious volumetric area of the geodesic domes.

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